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Atmospheric Infrared Sounder

AIRS CO2 Retrievals Using the Method of Vanishing Partial Derivatives (VPD)

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Luke Chen and Nir Krakauer

Jet Propulsion Laboratory
And
California Institute of Technology

AIRS Science Team Meeting
Caltech – Pasadena, CA
March 7-10, 2006

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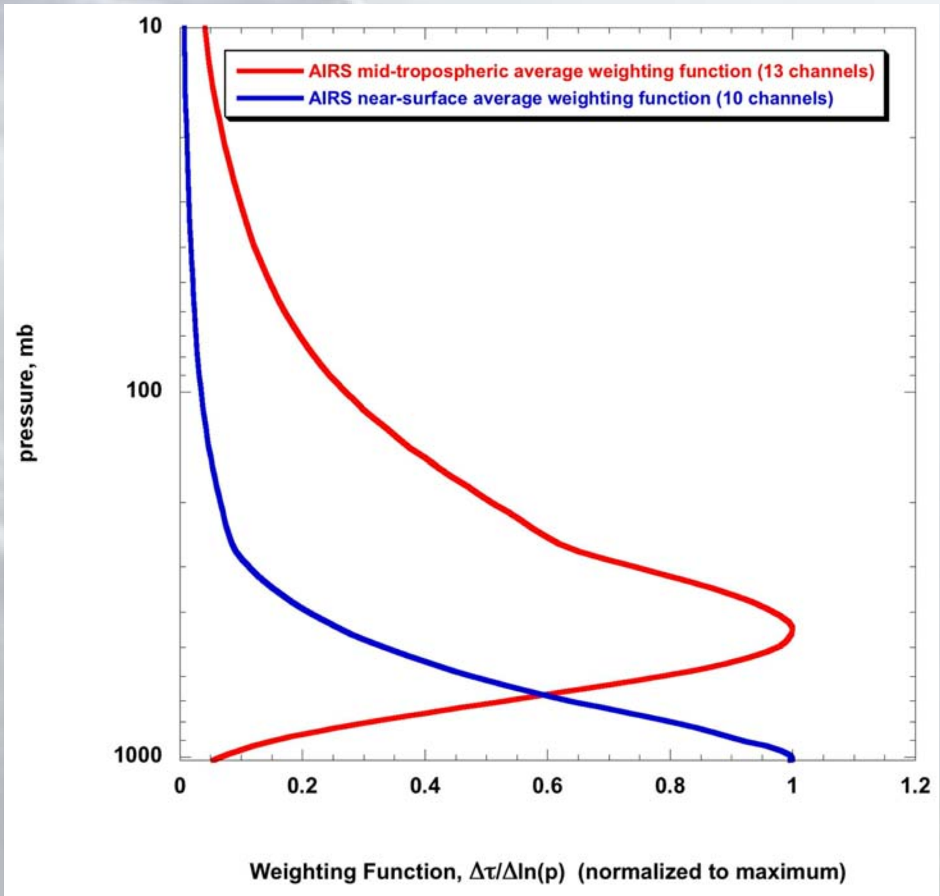
Atmospheric Infrared Sounder

AIRS CO_2 Sounding Channels Average Weighting Functions



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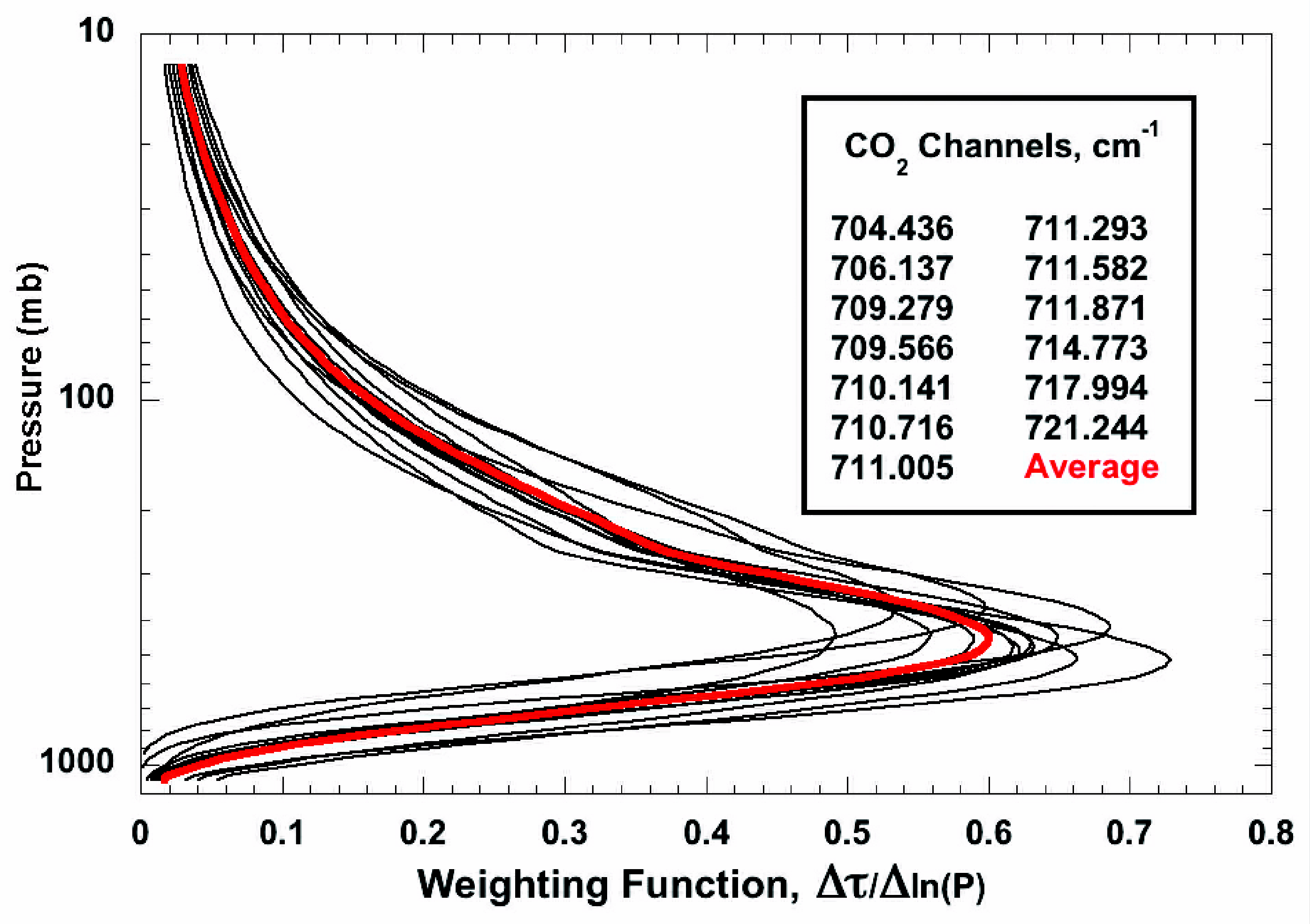
CO_2 Sounding Channels Individual Weighting Functions



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Atmospheric Infrared Sounder

Paper in GRL (November 18, 2005)

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GEOPHYSICAL RESEARCH LETTERS, VOL. 32, L22803, doi:10.1029/2005GL024165, 2005

On the determination of atmospheric minor gases by the method of vanishing partial derivatives with application to CO_2

M. Chahine,[1] C. Barnet,[2] E. T. Olsen,[1] L. Chen,[1] and E. Maddy[3]

Received 22 July 2005; revised 3 October 2005; accepted 11 October 2005; published 18 November 2005.

[1] We present a general method for the determination of minor gases in the troposphere from high spectral resolution observations. In this method, we make use of a general property of the total differential of multi-variable functions to separate the contributions of each individual minor gas. We have applied this method to derive the mixing ratio of carbon dioxide in the mid-troposphere using data from the Atmospheric Infrared Sounder (AIRS) currently flying on the NASA Aqua Mission. We compare our results to the aircraft flask CO_2 measurements obtained by H. Matsueda et al. over the western Pacific and demonstrate skill in tracking the measured 5 ppmv seasonal variation with an accuracy of 0.43 ± 1.20 ppmv. **Citation:** Chahine, M., C. Barnet, E. T. Olsen, L. Chen, and E. Maddy (2005), On the determination of atmospheric minor gases by the method of vanishing partial derivatives with application to CO_2, *Geophys. Res. Lett.*, *32*, L22803, doi:10.1029/2005GL024165.

1. Introduction

2. General Approach

[3] We consider the radiative transfer equation

$$R(\nu) = S_s(\nu, \varepsilon_s, \ldots) + \int_{p_s}^{0} B[\nu, T(p)] \left(\frac{\partial \tau(\nu, p, \langle \ldots \rangle)}{\partial p} \right) dp \quad (1)$$

where $R(\nu)$, the outgoing radiance at frequency ν measured at the satellite, is the sum of emissions from the surface and the atmosphere. Here ε_s is the surface emissivity, B the Planck blackbody function, τ the transmission function from any pressure level p to the top of the atmosphere and the angle bracket $\langle \ldots \rangle$ denotes a function of the profiles of temperature T(p), water vapor q(p), ozone O_3(p), carbon dioxide mixing ratio CO_2(p), etc. In this paper, we express the outgoing radiance $R(\nu)$ in brightness temperature units, $\Theta(\nu)$, in order to simplify its use across a wide range of frequencies.

RECENT PAPERS

Barnet, C.D., M. Goldberg, L. McMillin and M.T. Chahine (2004), Remote sounding of trace gases with the EOS/AIRS instrument, *Proceedings of SPIE, 5548*, 300-312.

Chedin, A., R. Saunders, A. Hollingsworth, N.A. Scott, M. Matricardi, J. Etcheto, C. Clerbaux, R. Armante and C. Crevoisier (2003), The feasibility of monitoring CO2 from high-resolution infrared sounders. *J. Geophys. Res. 108,* 4064-4071, doi:10.1029/2001JD001443.

Crevoisier, C., A. Chedin and N.A. Scott (2003), AIRS channel selection for CO2 and other trace-gas retrievals, *Q. J. R. Meteorol. Soc. 129*, 2719-2740.

Crevoisier, C., S. Heilliette, A. Chedin, S. Serrar, R. Armante and N.A. Scott (2004), Midtropospheric CO2 concentration retrieval from AIRS observations in the tropics, *Geophys. Res. Lett. 31,* 17106-17110, doi:10.1029/2004GL020141.

Engelen, R.J. and G.L. Stephens (2004a), Information content of infrared satellite sounding measurements with respect to CO2, *J. Appl. Meteor. 43*, 373-378.

Engelen, R.J., E. Andersson, F. Chevallier, A. Hollingsworth, M. Matricardi, A. P. McNally, J.-N. Thépaut, and P. D. Watts (2004b), Estimating atmospheric CO2 from advanced infrared satellite radiances within an operational 4D-Var data assimilation system: Methodology and first results. *J. Geophys. Res.*, *109*, D19309, doi:10.1029/2004JD004777.

Engelen, R.J. and A. P. McNally (2005), Estimating atmospheric CO2 from advanced infrared satellite radiances within an operational 4D-Var data assimilation system: Results and validation. *J. Geophys. Res*. (in press), doi:10.1029/2005JD005982.

Method of Vanishing Partial Derivatives (VPD)

In GRL, November 18, 2005

We consider the case where observations are made in a spectral region in the infrared where several minor gases such as CO_2, O_3, CO, CH_4 and SO_2 are radiatively active.

We define the residual function *G* as

$$G^{(n)} = \sum_{\nu} [\Theta_M(\nu) - \Theta_C^{(n)}(\nu)]^2$$

We aim to find the set of X_i which minimizes the residual function. We express the total differential of G as

.

$$dG = \frac{\partial G}{\partial X_1} dX_1 + \frac{\partial G}{\partial X_2} dX_2 + \frac{\partial G}{\partial X_3} dX_3 + ... + \frac{\partial G}{\partial X_i} dX_i + \varepsilon \qquad \textbf{(3)}$$

From the general property of total differentials, the condition that *G* in equation (4)

should have a maximum or a minimum at a point ($\overline{X}_i^{(1)}$, $\overline{X}_2^{(1)}$,$\overline{X}_3^{(1)}$,$\overline{X}_i^{(1)}$) is that

each of the first partial derivatives should individually vanish at that point.

$$\frac{\partial G}{\partial X_1}, \frac{\partial G}{\partial X_2}, \frac{\partial G}{\partial X_3}, ..., \frac{\partial G}{\partial X_i} \qquad \textbf{(4)}$$

Thus we reach an important conclusion *that the value of the individual mixing ratio of each of the minor gases considered is determined by the value that makes their first partial derivative in equation (4) vanish <u>individually</u>.* Therefore, even though the observed spectra cannot differentiate between the individual lines, the partial differentials can!

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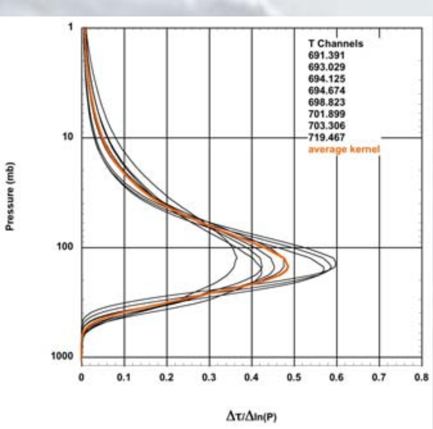
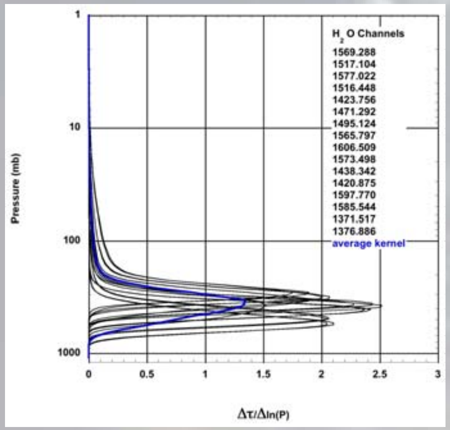
Atmospheric Infrared Sounder

Auxiliary Sounding Channels Individual Weighting Functions

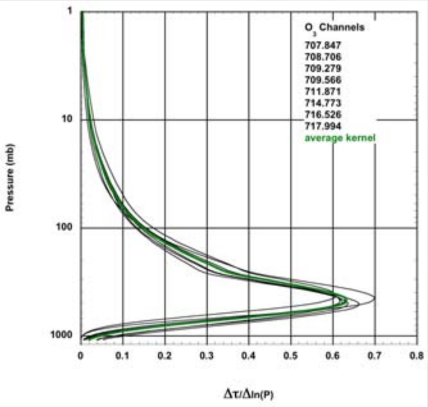
Temperature



Water vapor

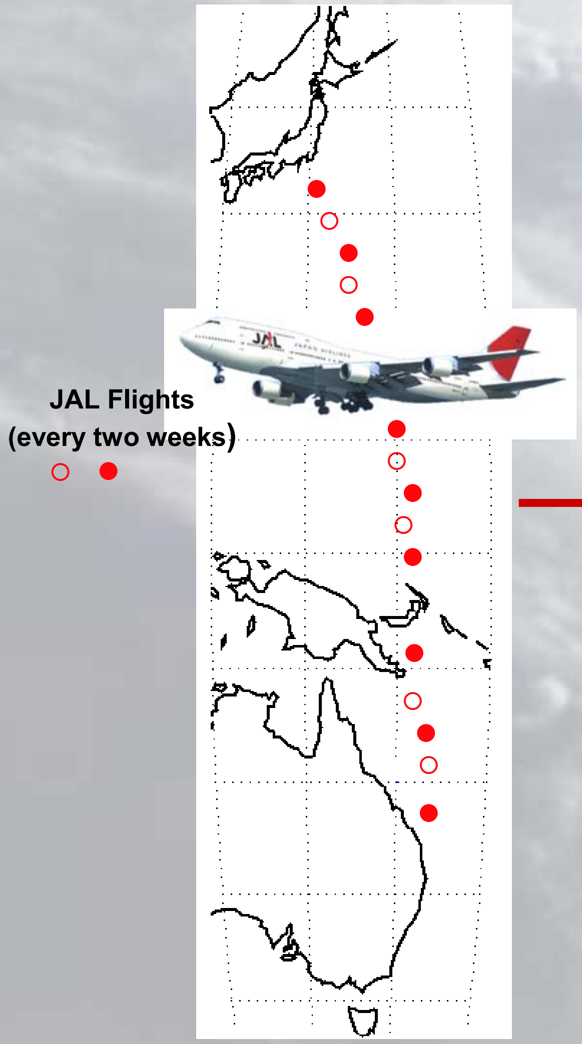


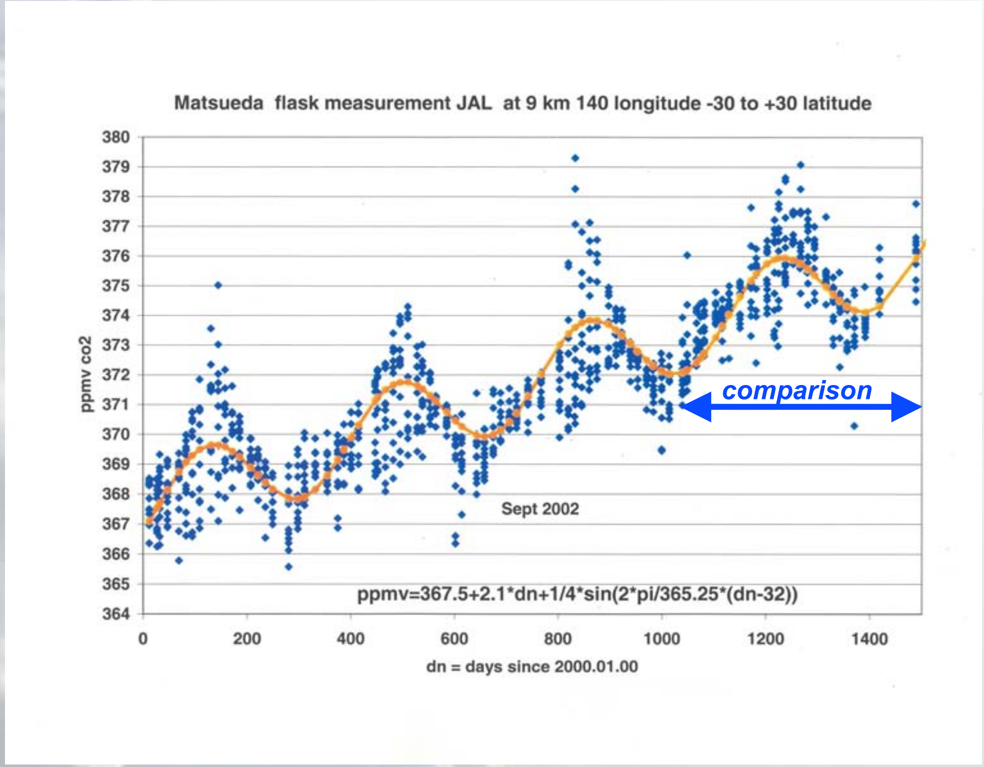
Ozone



Matsueda Airborne Flask

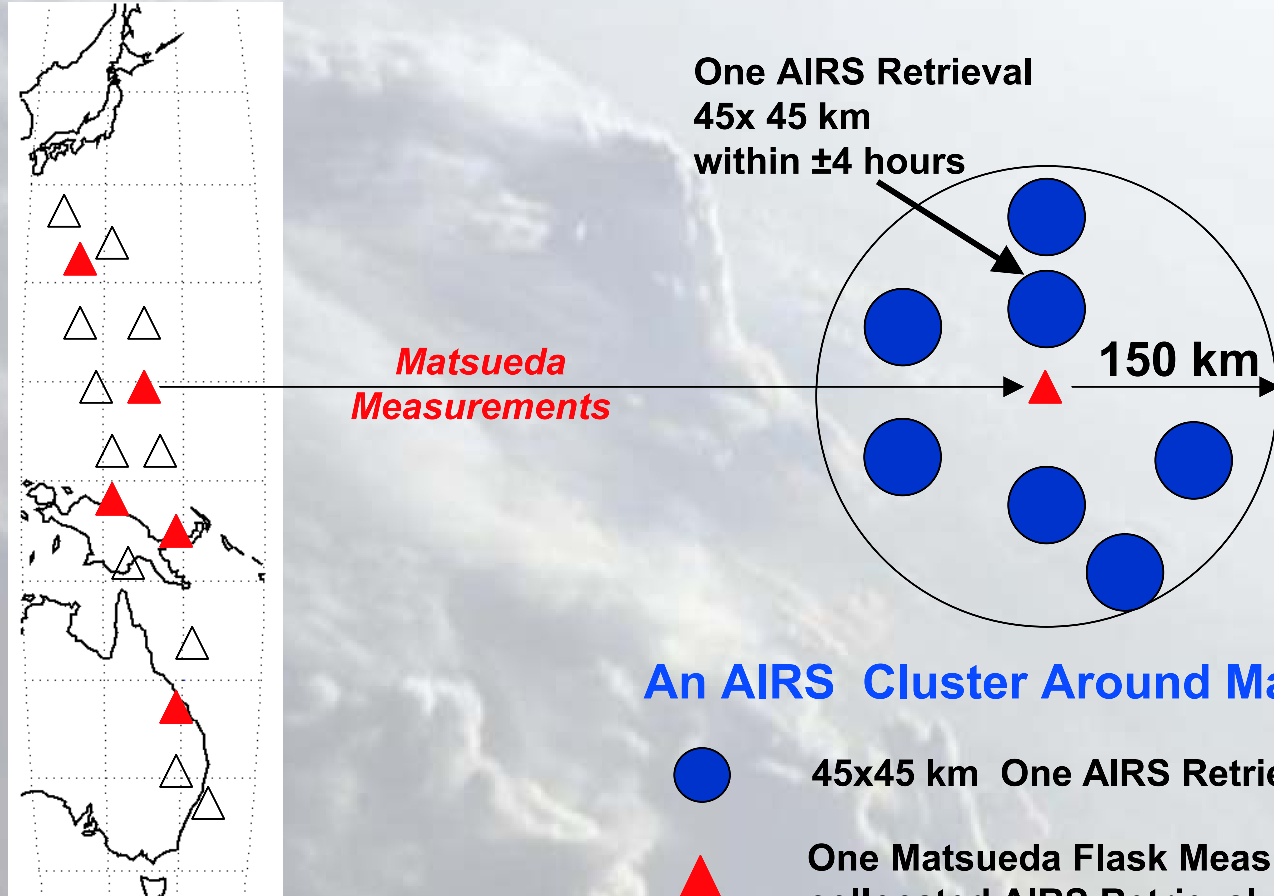
CO_2 Measurements at 10.5 km altitude





Matsueda Airborne Flask
CO_2 Measurements
at 10.5 km altitude

Collocated AIRS
CO_2 Retrievals
at 5-15 km altitude



An AIRS Cluster Around Matsueda

45x45 km One AIRS Retrieval

One Matsueda Flask Measurement with collocated AIRS Retrieval

A Total of 2332 AIRS Retrievals (*in the presence of clouds*) found Collocated with 223 Matsueda measurements

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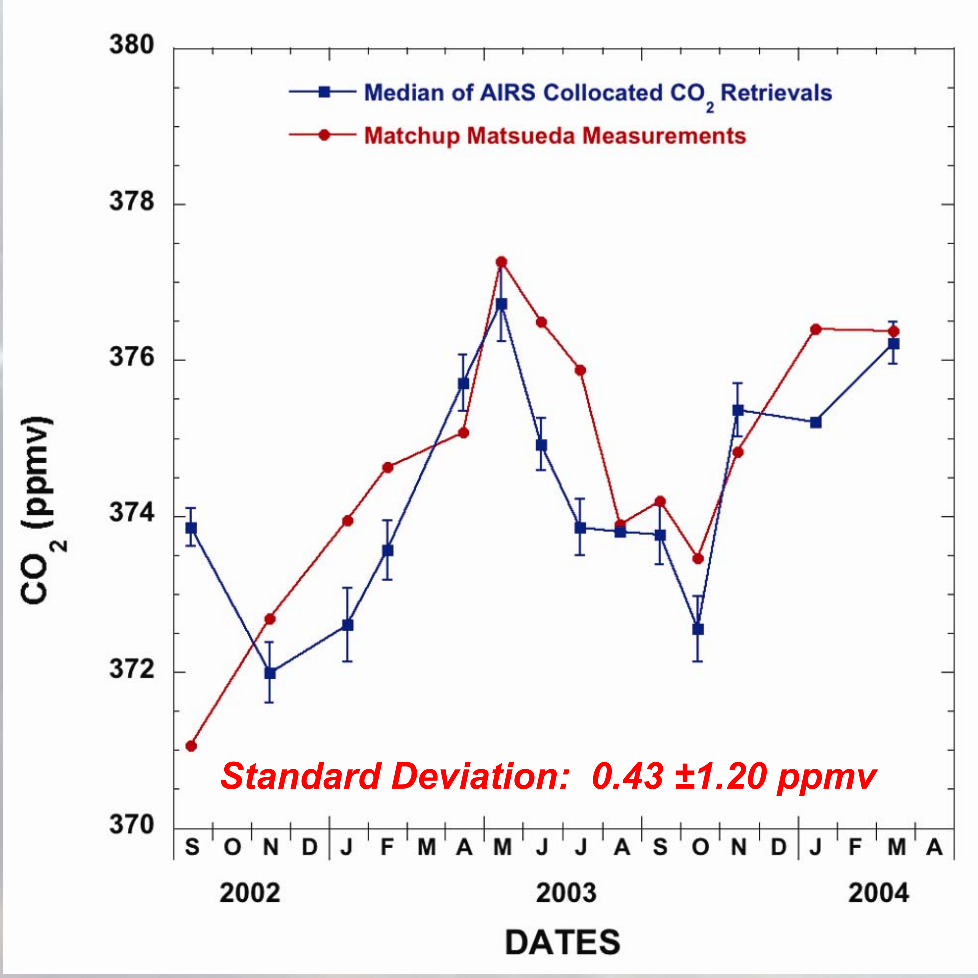
Validation of AIRS CO2 Results

Comparison of AIRS CO_2 Retrievals with Collocated Matsueda Flask Measurements

(Collocation Criteria: ± 4 hours and 150 km radius around Matsueda)



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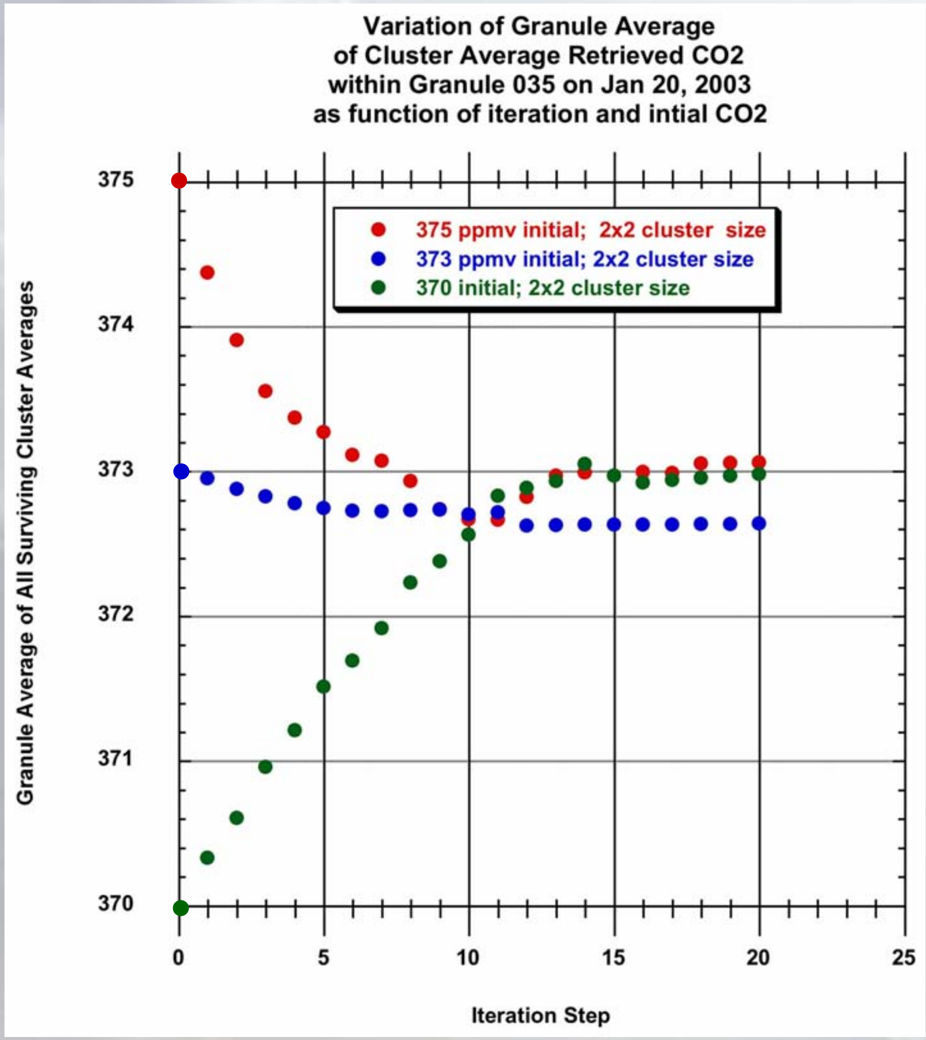
Independence of the solution

from Initial starting value of the CO2 Mixing Ratio

370 373 375 *ppmv*

Starting Number of Clusters of ~210



Remaining Clusters

- 140
- 200
- 130

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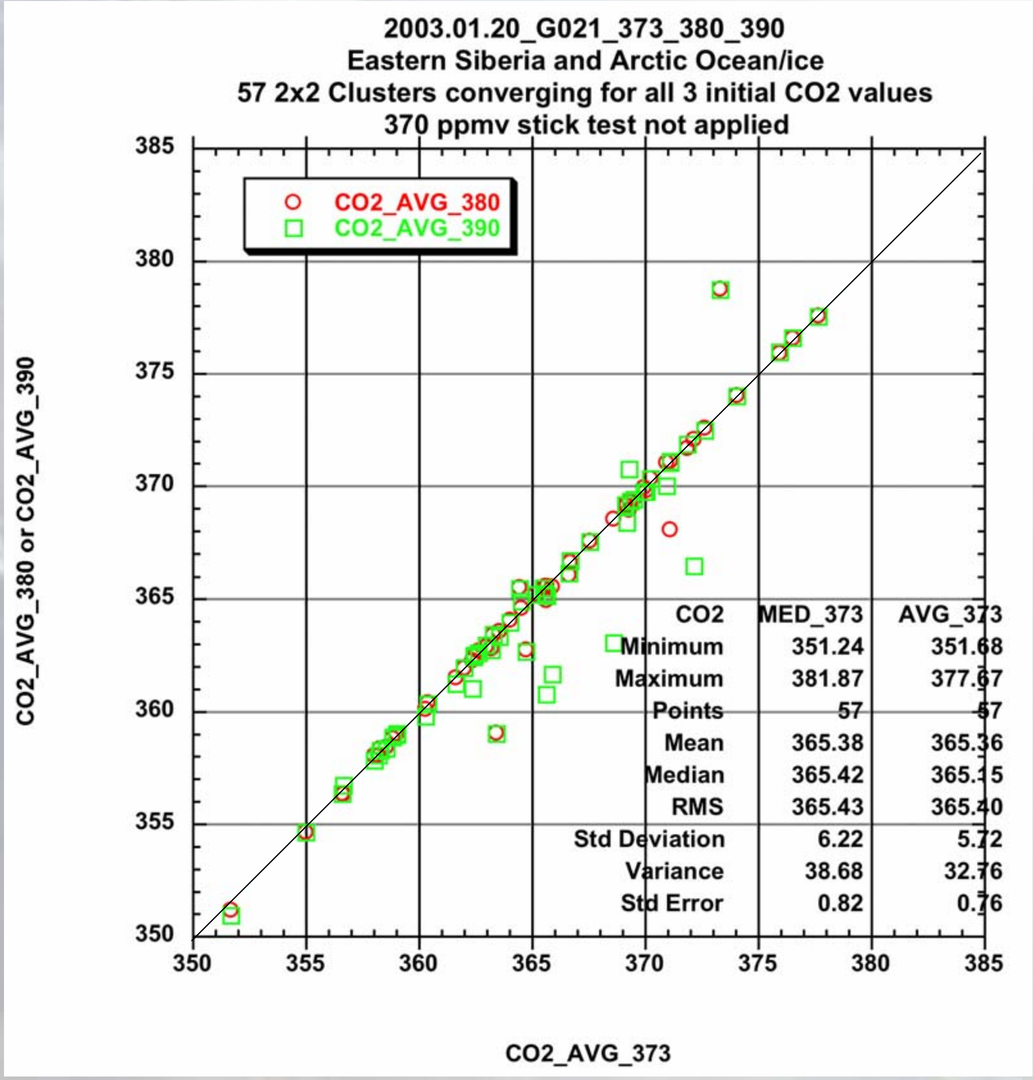
Independence of the solution

from Initial starting value of the CO2 Mixing Ratio



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Atmospheric Infrared Sounder

Estimating atmospheric CO_2 from advanced infrared radiances with an operational 4D-Var data assimilation system: Results and Validation

Richard J. Engelen and Anthony P. McNally

Abstract. More than a year of AIRS radiance observations have been assimilated in the ECMWF 4D-Var data assimilation system to estimate tropospheric CO_2. The assimilation of a set of eighteen spectral channels provides a mean tropospheric mixing ratio representing a layer between about 700 hPa and the tropopause. Analysis errors for a 5-day mean on a 6° by 6° averaging grid box are on the order of 1%. Comparisons with independent flight data from JAL and NOAA/CMDL are favourable. Differences between the averaged assimilation estimates and the onboard flask observations are generally within the 1-σ error bars. Currently, this work is being extended by introducing CO_2 as a full assimilation model tracer variable, which will allow the operational monitoring of atmospheric CO_2 using AIRS observations and observations from upcoming instruments.

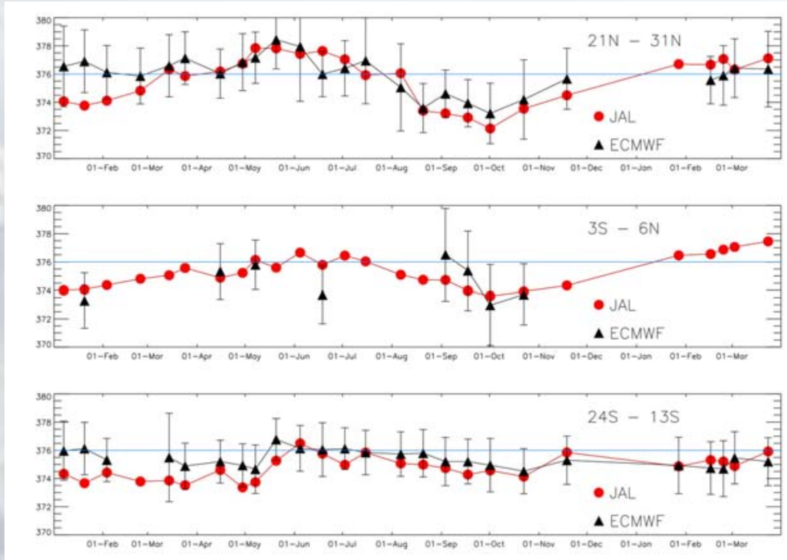

Figure 6. Comparison of CO_2 estimates with JAL observations for three different latitude zones from January 2003 to March 2004. Missing ECMWF data are caused by extensive cloud cover in the area.

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Atmospheric Infrared Sounder

Midtropospheric CO_2 concentration retrieval from AIRS observations in the tropics

Crevoisier, S Heilliette, A. Chedin, S. Serrar, R. Armante and N.A. Scott

(Using Neural networks method)

[1] Midtropospheric carbon dioxide (CO_2) concentration is retrieved in the tropics [20S:20N], over sea, at night, for the period April to October 2003 from the Atmospheric Infrared Sounder (AIRS) observations. The method relies on a non-linear regression inference scheme using neural networks. A rough estimate of the mean precision of the method is about 2.5 ppmv (0.7%). The retrieved seasonal cycle and its latitudinal dependence agree well with aircraft CO_2 in situ measurements made at the same altitude range. Maps produced on a monthly basis at a resolution of 15° × 15°, although not yet fully understood, show good agreement with known characteristics of CO_2 distribution reflecting both atmospheric transport and surface fluxes

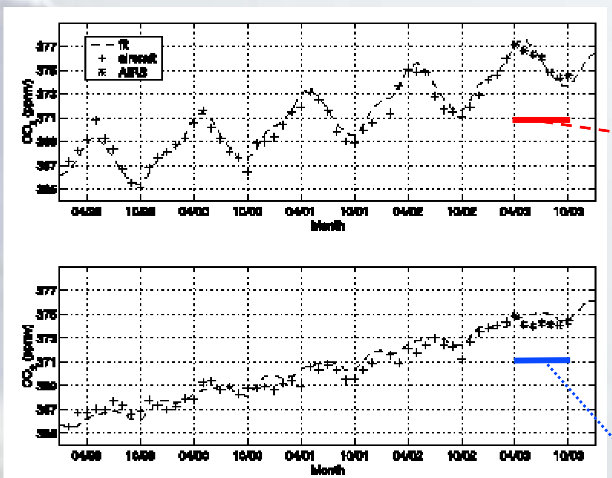
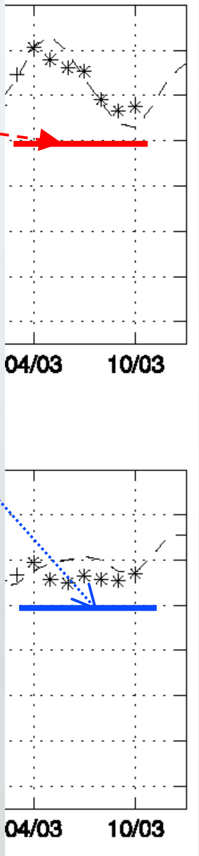


Figure 2. Monthly mean CO_2 concentration as retrieved in the tropics from AIRS observations for the period April–October 2003 (stars), and as observed by aircraft measurements for the period January 2001–March 2003 (crosses). The dashed lines represent the sum of the linear trend and the harmonics (see text). Top: northern tropics; bottom: southern tropics. A scalar offset of −0.9 ppmv was added to AIRS retrievals (see text).



GRL VOL. 31, L17106, doi:10.1029/2004GL020141, 2004

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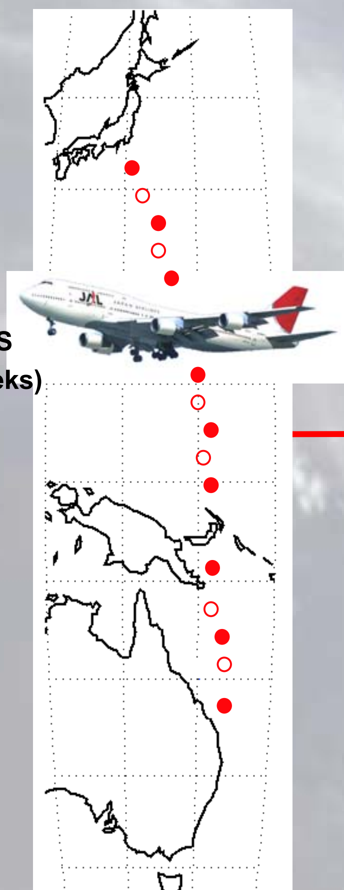
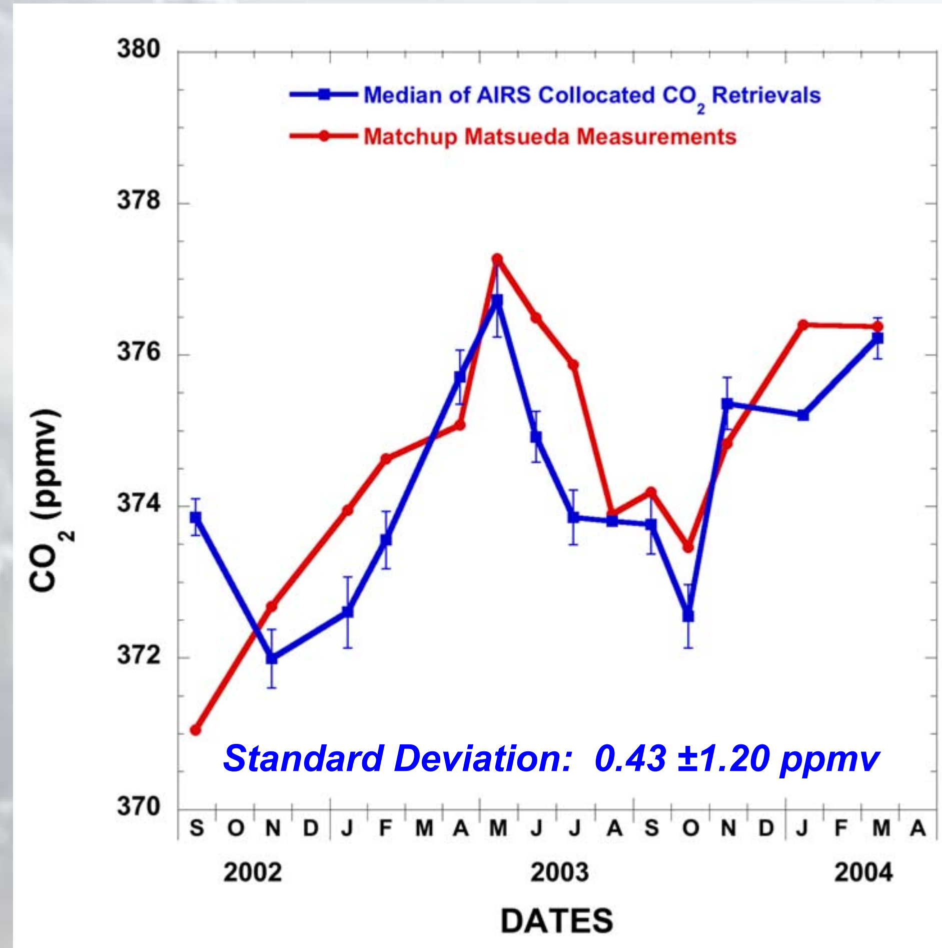
SUMMARY

Comparison of AIRS CO_2 Retrievals with collocated Matsueda Flask Measurements

(Colocation Criteria: ± 4 hours and 150 km radius around Matsueda)

JAL FLIGHTS
(Every two weeks)





NEXT: GENERATE GLOBAL MAPS OF CO2 DISTRIBUTION

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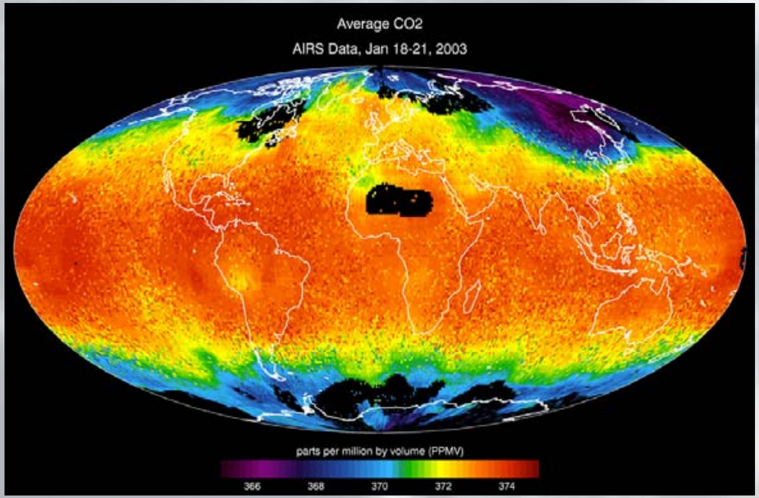
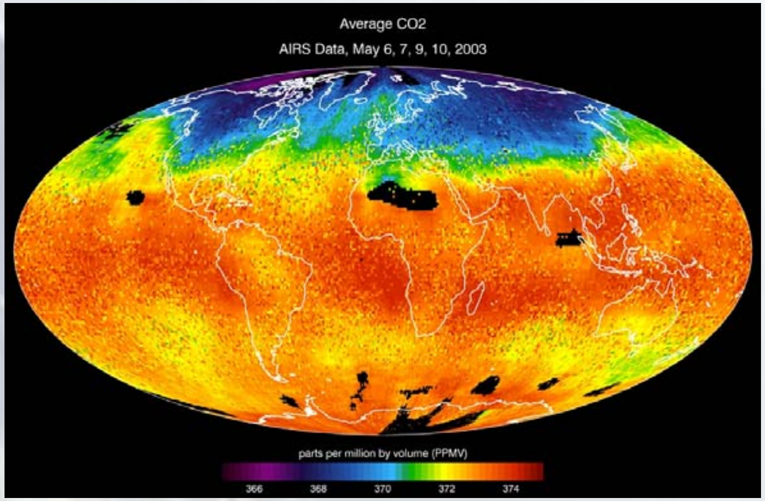
Atmospheric Infrared Sounder

AIRS Global CO_2 Maps

2003

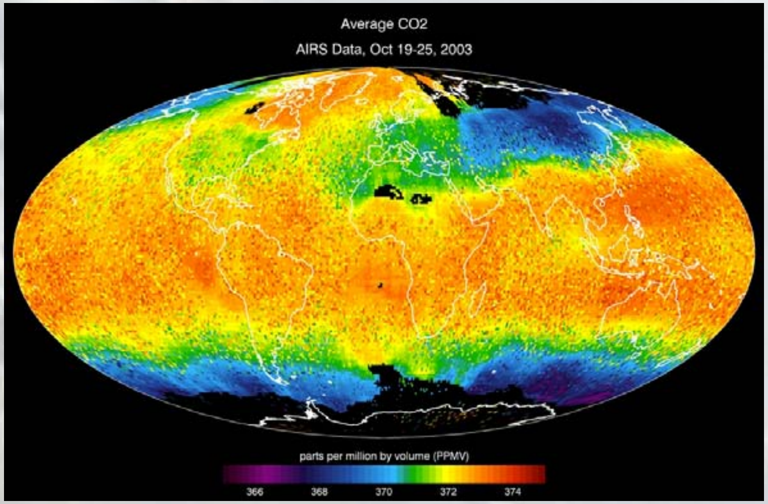




January 18-21

May 6-19

October 19-25



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